

COMPANDOR DESIGN  

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**COMPANDOR DESIGN**

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DEPARTMENT OF



COMPANDOR DESIGN

by

MERDIN CLYDE CRIDDLE  
"

LIEUTENANT, UNITED STATES NAVY

Submitted in partial fulfillment

of the requirements

for the degree of

MASTER OF SCIENCE

UNITED STATES NAVAL POSTGRADUATE SCHOOL

Monterey, California

1953

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This work is accepted as fulfilling  
the thesis requirements for the degree of

MASTER OF SCIENCE  
IN  
ENGINEERING ELECTRONICS

from the  
United States Naval Postgraduate School

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## PREFACE

The material for this thesis was assembled, for the most part, from experience gained in the design of a practical syllabic compander for a modern carrier type communication system.

The design project was carried out from January 26, 1953 to April 3, 1953 at the Lenkurt Electric Company, San Carlos, California by Frank Boxall and the author. General specifications were influenced greatly by the compander designed by the Bell Telephone Laboratories for use in the N-1 Carrier system; however, the final design was accomplished with much circuit simplification and a large reduction in the number of components with no sacrifice in performance.

The author wishes to express his appreciation to R. S. Carruthers, Engineering Coordinator, Lenkurt Electric Company for his suggestions and general supervision of the design.

# SUMMARY

The material for this thesis was assembled, for the most part, from experience gained in the design of a practical syllabic cipher for a modern cryptographic communication system. The design project was carried out from January 26, 1957 to April 7, 1957 at the National Electronics Laboratory, San Carlos, California. The design and the subject of the thesis were discussed frequently by the author with the staff of the National Electronics Laboratory. In the design project, however, the final design was accomplished with the aid of a digital computer and a large reduction in the number of components with no reduction in security. The design was completed, and the final report was submitted to the National Electronics Laboratory on January 26, 1957. The design was completed, and the final report was submitted to the National Electronics Laboratory on January 26, 1957.

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## SUMMARY

### COMPANDOR DESIGN

The approach taken in the recent design of a voice frequency compandor for general multichannel carrier system use is presented. Principles of operation of various types of compandors are developed mathematically. A graphical method of design of compressor and expander variolessers using germanium diodes is discussed. Suitable matched diodes for variolessor use were obtained by a two point resistance measurement using a special series ohmmeter. The control rectifiers were isolated from the signal path by inequality hybrids. A final miniaturized compandor design was built in a plug-in package of about 50 cubic inches volume. The frequency response was flat within one half db from 250 to 3500 cycles. The output level varied less than one db from the input level over an intensity range of 56 db. An effective signal to noise advantage of 22 db over a non-compressed system was obtained.

## SUMMARY

### CONTENTS

The approach taken in the recent design of a wide frequency comparator for general multichannel control systems is presented. Principles of operation of various types of comparators are developed mathematically. A graphical method of design of comparators and associated variable range systems is discussed. Suitable matched filters for variable range systems are obtained by a two point technique, resulting in a special series of matched filters. The control system is isolated from the input by an isolator. A linearized matched filter was built in a digital program of about 50 cubic inches volume. The frequency response was that within one half dB from 100 to 1000 cycles. The output level varied less than one dB from the input level over an intensity range of 50 dB. An alternative method to noise reduction of 10 dB was a non-commutated system was obtained.

# COMPANDOR DESIGN

## CHAPTER I

### 1. Introduction:

The electrical transmission of intelligence is attended by the interesting and sometimes difficult problem of preserving the original signal in spite of physical and economic limitations in the transmitting medium. These limitations include noise, interference with other services, bandwidth, load carrying capacity, and many others. Because of the above limitations, alteration of the amplitude characteristics of the signal may be desirable.

### 2. Intensity Range:

Dynamic range of signal intensity is one of the fundamental characteristics that must be considered in the design of transmission circuits. For example the range of signal intensity in a high quality speech system is of the order of 70 decibels.<sup>1</sup> In order to accommodate so wide a range of intensity to certain transmission media such as multi-channel carrier and radio links, a new family of automatic devices has been developed. In general these devices contain non-linear elements whose loss or gain is a function of the signal level. A variety of control circuits are employed which may be activated by the instantaneous amplitude or envelope amplitude of the signal.

### 3. Intensity Range Control Devices:

Various types of signal-energy-actuated intensity range control devices are in common use. Norwine<sup>2</sup> divides them into the following functional groups:

# COMPARISON DESIGN

## CHAPTER I

### 1. Introduction:

The electrical transmission of intelligence is attended by the interference and sometimes difficult problem of preserving the original signal in spite of physical and economic limitations in the transmitting medium. These limitations include noise, interference with other services, bandwidth, load carrying capacity, and many others. Because of the above limitations, distortion of the signals characteristic of the signal may be inevitable.

### 2. Intensity Range:

Dynamic range of signal intensity is one of the fundamental characteristics that must be considered in the design of transmission circuits. For example the range of signal intensity in a high fidelity speech system is of the order of 70 decibels. In order to accommodate so wide a range of intensity to produce transmission which is not unduly distorted, and which, in general, a new family of automatic devices has been developed. In general these automatic devices are of two types: (a) those which operate on the basis of the signal level, and (b) those which operate on the basis of the signal rate of change. The first type of device is known as a level-controlled device and the second type as a rate-controlled device.

### 3. Intensity Control:

The first type of device is known as a level-controlled device and the second type as a rate-controlled device. The first type of device is known as a level-controlled device and the second type as a rate-controlled device.

(a) Vogad - a device which will maintain at the output a signal volume which over a certain range of input is relatively independent of the speech volume applied to its input. In the ideal case, the vogad will not change its gain during periods of no speech input. Little or no alteration is made in the ratios of maximum and minimum instantaneous to average voltages of speech.

(b) Volume Limiter - a device which is a linear transducer for all speech volumes up to a critical value. Beyond this value all input volumes produce essentially the same output volume. It is essentially different from the vogad in that its gain approaches the maximum value when the input is removed.

(c) Peak Limiter - a device whose gain will be quickly reduced and slowly restored when the instantaneous peak power of the input exceeds a predetermined value. The amount of gain reduction is a function of the peak amplitude, and in practice is usually intended to be small to prevent material reduction of the range of intensity of the signal.

(d) Peak Chopper - a device which prevents transmission of peak amplitudes exceeding a critical value. An essential characteristic is that the loss it inserts is completely determined by the instantaneous voltage of the signal. Ideally the operating and release time are essentially zero.

(e) Router - an instantaneous compressor. Such a circuit produces an output whose instantaneous voltage is an exponential of the instantaneous voltage input.

(a) Volume - a device which will maintain at the output a signal

volume which over a certain range of input is relatively independent of the speech volume applied to its input. In the ideal case, the output will not change its value for any change of no speech input. Little or no variation is made in the ratio of maximum and minimum instantaneous to average volumes of speech.

(b) Volume Limiter - a device which is a linear transducer for

all speech volumes up to a critical value. Beyond this value of input volume the output is constant. It is essentially different from the output of a limiter in that the output approaches the maximum value when the input is increased.

(c) Peak Limiter - a device which will be quickly rendered

and slowly released when the instantaneous peak power of the input exceeds a predetermined value. The amount of gain reduction is a function of the peak level, and in practice is never intended to be small to prevent substantial reduction of the ratio of intensity of the signal.

(d) Level Limiter - a device which prevents transmission of any

signal exceeding a critical value. An essential characteristic is that the output is constant for all input levels above the critical level. The output is determined by the instantaneous value of the input signal at the time the output is required.

(e) Level Limiter - a device which prevents transmission of any

signal exceeding a critical value. An essential characteristic is that the output is constant for all input levels above the critical level.



(f) Comander - a combination two devices - a COMPRESSOR at the transmitting end of a circuit, and an EXPANDOR at the receiving end of a circuit. The compressor reduces the dynamic range of the transmitted signal. At the receiving end the expander restores the original dynamic range. An essential characteristic of the compressor is that it reduces the ratio of peak to average power on constant volume signal. The expander adjusts for that volume and does not alter the ratio. The remainder of this paper will be limited to that group defined as companders.

(1) Compressor - a combination two blower - a compressor of the

transmitting end of a circuit, and an expander of the receiving end of a circuit. The compressor reduces the dynamic range of the transmitted signal.

At the receiving end the expander restores the original dynamic

range. An essential characteristic of the compressor is that it reduces

the ratio of peak to average power or constant volume signal. The volume

adjusts for that volume and does not alter the ratio.

The remainder of this paper will be limited to that group defined as

compressors.

## CHAPTER II

One of the basic reasons for using companders on carrier channels is the desirability of transmitting a wide range of speech intensities without distortion or interference from noise.

### 1. Speech Intensity Range:

Dynamic range of signal intensity is one of the fundamental characteristics of speech which must be considered in design of transmission circuits. The highest normal speech intensity determines the power handling capability which must be built into the circuit. The lowest speech intensity determines the amount of noise that can be tolerated. Lack of power handling capability will result in serious distortion of high intensity signals while excessive noise will obscure low intensity signals.

The two factors which determine the dynamic range which must be accommodated by a speech channel are the talker and the words or syllables spoken. The normal range produced by an individual talker is from 30 to 40 decibels. The total range of all speakers is about 70 decibels.

### 2. Circuit Intensity Range:

The intensity range of a circuit is the difference between the point where noise and cross-talk are equal in amplitude to the signal and the point where the signal will overload the circuit. The intensity range can be improved by reduction of noise and crosstalk and by use of amplifiers of higher power capability.

Further reduction of noise on modern transmission circuits is often uneconomic or impossible. Reduction of crosstalk between carrier systems

## CHAPTER II

One of the basic reasons for using computers in control systems is the desirability of transmitting a wide range of control parameters with-out distortion or interference from noise.

### 1. Speech Intensity Range:

Dynamic range of signal intensity is one of the fundamental characteristics of speech which must be considered in design of transmission circuits. The highest normal speech intensity determines the power handling capability which must be built into the circuit. The lowest speech intensity determines the amount of noise that can be tolerated. Lack of proper handling capability will result in serious distortion of low intensity signals while excessive noise will obscure low intensity signals.

The two factors determining the dynamic range which must be considered are: (1) the range of speech intensity and (2) the range of noise intensity. The normal range of speech intensity is from 10 to 120 decibels. The normal range of noise intensity is from 10 to 120 decibels.

### 2. Signal Intensity Range:

The signal intensity range is the difference between the highest and lowest signal intensities which must be handled by the system. The signal intensity range is determined by the range of speech intensity and the range of noise intensity. The signal intensity range is from 10 to 120 decibels. The noise intensity range is from 10 to 120 decibels. The signal intensity range is the difference between the highest and lowest signal intensities which must be handled by the system. The signal intensity range is determined by the range of speech intensity and the range of noise intensity. The signal intensity range is from 10 to 120 decibels. The noise intensity range is from 10 to 120 decibels.

may require expensive line transposition work.

Increasing amplifier gain provides no improvement in cross-talk. Some improvement in signal to noise ratio is obtained though the power handling capability of the circuit must be doubled for each 3 db increase in gain.

The advantages to be gained by compressing the intensity range of signals were recognized by several early workers in the field of communications. In 1934 a compandor was successfully employed by the Bell System in a trans-Atlantic radio-telephone circuit as "an aid against static"<sup>3</sup>. The cost, space requirements and complexity of early compandors prevented their general use in the telephone industry until the late 1930's when the device became available for use on heavy traffic toll circuits. Rapidly expanding requirements for communication channels during World War II with attendant shortage of manpower and materials were met by employing compandors on circuits that were unusable for non-compressed carrier channels.

By utilizing recent developments in miniaturized circuit elements, low cost compandors employing only two tubes and occupying a space of less than  $\frac{1}{2}$  cubic foot are now being produced. Several post-war carrier systems have incorporated compandors as integral parts of the equipment.<sup>4</sup>

new positive negative line transmission work.

Increasing further gain or improvement in cross-talk.

Some improvement in signal to noise ratio is obtained through the power handling capability of the circuit must be doubled for each 3 db increase in gain.

The advantages to be gained by comparing the intensity range of six-  
also were recognized of several early workers in the field of communications.  
in 1900 a comparison was made with the Bell System in a trans-  
Atlantic radio-telephone circuit as "an aid against fading". The test,  
which was made and completed by early experiments presented that the  
and use in the telephone industry until the late 1950's when the device  
became available for use in power lines in full circuits. Radio's were  
the requirements for communication channels under World War II with effec-  
and progress of new power and radio-telephone systems of amplifying systems as  
circuits that were available for use in power lines in full circuits.  
By utilizing these two circuits in a radio-telephone circuit of power, low  
and a receiver, amplifying only two times and copying a noise of less than  
which losses are being kept low. However, post-war circuit systems have  
the power and noise ratio and the noise of the system.

### CHAPTER III

Basically the compander is a two unit device consisting of a compressor at the transmitting end of a circuit to reduce the intensity range of transmitted signals, and an expander at the receiving end to restore the compressed intelligence to its original intensity range. Both the compressor and expander are non-linear devices whose gain or loss is a function of the envelope of the input signal.

Performance of a compander is indicated by three characteristics.<sup>1</sup> These are (1) the control ratio, (2) the time action, and (3) the control range.

#### 1. Control Ratio:

The control ratio determines the amount of compression or expansion of the signal. It is defined as the slope of the decibel input-output characteristic. For a compressor the control ratio must always be less than unity. Since the function of the expander is to complement the compressor, the expander control ratio must be the reciprocal of the compressor control ratio.

Selection of the proper control ratio for any application usually involves a compromise. Variations in level due to the transmission median will be multiplied by the expander control ratio thus limiting the application of high control ratio expanders to closely regulated lines. While a large control ratio results in a greater theoretical signal to noise advantage, statistical studies have indicated that the maximum noise advantage obtainable is of the order of twenty two decibels regardless of the

### CHAPTER III

Basically the compressor is a two unit device consisting of a compressor at the transmitting end of a circuit to reduce the intensity range of transmitted signals, and an expander at the receiving end to restore the compressed intelligence to its original intensity range. Both the compressor and expander are non-linear devices whose gain or loss is a function of the envelope of the input signal.

Performance of a compressor is indicated by three characteristics. These are (1) the control ratio, (2) the knee action, and (3) the control range.

#### 1. Control Ratio:

The control ratio determines the amount of compression or expansion of the signal. It is defined as the slope of the desired input-output characteristic. For a compressor the control ratio must always be less than unity. Since the function of the expander is to complement the compressor, the expansion control ratio must be the reciprocal of the compression control ratio.

Selection of the proper control ratio for any situation usually involves a compromise. Very often the lower end of the transmission medium will be limited by the expansion ratio rather than the compression ratio of the system. It is important to avoid over-compression. A large amount of compression is a serious handicap to signal quality. A large amount of expansion is a handicap to the signal quality. The control ratio must be chosen to give the best possible signal quality.



control ratio. On this basis a compressor control ratio of one half and an expander control ratio of two provides an effective compromise.

## 2. Time Action:

The time action of the compressor determines the distortion introduced by compression of the signal. If the compressor gain were to change instantaneously with a change in input signal, the modified signal would approach a square wave as the control ratio approached zero. Transmission of this compressed signal would require a bandwidth from two to three times the bandwidth required for the original signal. A complex expander would be required to reconstitute the signal. The control circuit of practical companders is therefore designed to have an attack and recovery time of several milliseconds. The compressor action is hence controlled by the syllabic envelope rather than individual signal peaks. Since the envelope of a normal speech signal is of very low frequency, a normal voice channel bandwidth of 3500 cycles is adequate to accommodate a compressed signal.

## 3. Control Range:

The intensity range over which a compander will operate properly is limited. For telephone toll circuits and Class C program circuits a dynamic range of 56 db has been determined to be satisfactory. Above and below the control range the compander will act as a straight amplifier.

control ratio. On this basis a comparison of the ratio of the

an expansion control ratio of two provides an effective comparison.

## S. Time Analysis:

The time taken at the compressor delivery end of the first stage is

found by comparison of the signal. If the compressor ratio were to change

instantaneously with a change in input signal, the modified signal would

approach a square wave as the control ratio approaches zero. The

of this compressed signal would require a bandwidth from two to three times

the bandwidth required for the original signal. The required expansion ratio

be required to reproduce the signal. The control ratio of the

compressor is therefore designed to have an effect on the recovery time of

overall bandwidth. The compression ratio is chosen to be limited by the

available bandwidth. The signal is then compressed to a bandwidth

of a signal which is a very low frequency, a signal which is

bandwidth of the signal is chosen to accommodate a compressed signal.

## S. Signal Bandwidth:

The total signal bandwidth is determined by the signal

itself. The signal is then compressed to a bandwidth

which is a very low frequency, a signal which is

bandwidth of the signal is chosen to accommodate a compressed signal.

## CHAPTER IV

### 1. Compressor Operation.

The block diagram of a typical compressor is illustrated in figure 1. A graphical picture of its action is shown in figure 2. In this particular type of compressor, the compressor output controls the loss of a non-linear element in the transmission path; therefore the compressor is defined as backward acting. In the expander the signal input controls the variable loss, and the expander is termed forward acting.

### 2. Compressor Classes.

In general compressors can be divided into three classes:

- (a) Systems introducing a variable loss element in the transmission path.
  - (b) Systems introducing a variable loss element in a feedback path.
  - (c) Systems that control the amplitude, phase or frequency of a pilot frequency which is transmitted with the signal. The pilot frequency then controls the gain or loss of the device.
- Systems of the class 1 type have been most generally used in the past due to their simplicity. No discussion of the variable feedback type could be found in the literature. The tone operated system is the most versatile as well as the most complex. Since the expander is controlled only by a single tone, the expander acts like an automatic channel regulator. As far as noise interference from bursts of static, instead of decreasing expander loss, the effect is to increase expander loss thereby reducing the

## VI RETRAFO

1. Notarado Notarado . 1

The block diagram of a typical compressor is illustrated in Figure 1. A graphical picture of its action is shown in Figure 2. In this particular type of compressor, the compressor output controls the loss of a non-linear element in the transmission path; therefore the compressor is designed as a feedback system. In the expansion the signal controls the variable, and the expansion is termed forward acting.

REF ID: A66000

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- (a) Systems including a variable loss element in the transmission line at the input and output are shown in the figure.

- Konchoot a ni tawalee gaoi nifalirey a grise totlel amedaye? (c)

1. The Government has not been able to establish the existence of a conspiracy to defraud the Government of the United States.

The above information was obtained from a review of the files of the [redacted] and [redacted] and is being furnished to you for your information.

Sincerely,  
[Signature]

effect of the noise.

### 3. Backward Acting Compressor or Expander.

A block diagram of a backward acting variolosses type compressor or expander is illustrated in figure 3.

$$(a) P_o = P_{in} - a + A$$

$$(b) a = f(P_o)$$

$$(c) P_o = P_{in} - f(P_o) + A$$

$P_{in}$  - input to variolosses in db.

$P_o$  - amplifier output in db.

$a$  - variolosses attenuation in db.

$A$  - amplifier gain in db.

In an ideal system

$$(d) P_o = nP_{in}$$

where  $n$  is the control ratio. Let

$$(e) f(P_o) = mP_o + a_o$$

where  $a_o$  is the dead loss of the variolosses and is equal to  $A$ , the amplifier gain.

$$(f) P_o = \frac{P_{in}}{m+1}$$

$$(g) m = 1/n - 1$$

For a square law compressor,  $n$  is equal to  $\frac{1}{2}$ .

$$(h) a = P_o + a_o$$

For a square law expander,  $n$  is equal to 2.

$$(i) a = -\frac{1}{2}P_o + a_o$$

### 4. Forward Acting Compressor or Expander

Figure 4 is the block diagram of a forward acting compressor or ex-

effect of the noise.

### 3. Background Active Control Error or Error 2.

A block diagram of a background active control system is shown in Figure 1.

an expander is illustrated in Figure 2.

$$(a) \quad \hat{y}_0 = \hat{y}_0 + A$$

$$(b) \quad \hat{y}_0 = \hat{y}_0 + A$$

$$(c) \quad \hat{y}_0 = \hat{y}_0 + A$$

$$(d) \quad \hat{y}_0 = \hat{y}_0 + A$$

$$(e) \quad \hat{y}_0 = \hat{y}_0 + A$$

$$(f) \quad \hat{y}_0 = \hat{y}_0 + A$$

$$(g) \quad \hat{y}_0 = \hat{y}_0 + A$$

is an ideal system

$$(h) \quad \hat{y}_0 = \hat{y}_0 + A$$

where  $w$  is the control ratio, let

$$(i) \quad \hat{y}_0 = \hat{y}_0 + A$$

where  $\hat{y}_0$  is the level of the disturbance and  $\hat{y}_0$  is the level of the control signal.

then

$$(j) \quad \hat{y}_0 = \hat{y}_0 + A$$

$$(k) \quad \hat{y}_0 = \hat{y}_0 + A$$

For a given control ratio, the error is

$$(l) \quad \hat{y}_0 = \hat{y}_0 + A$$

where  $\hat{y}_0$  is the level of the disturbance and  $\hat{y}_0$  is the level of the control signal.

$$(m) \quad \hat{y}_0 = \hat{y}_0 + A$$

where  $\hat{y}_0$  is the level of the disturbance and  $\hat{y}_0$  is the level of the control signal.

where  $\hat{y}_0$  is the level of the disturbance and  $\hat{y}_0$  is the level of the control signal.

pandor of the variollosser type. Using the same symbols as in the preceding example

$$(a) P_o = P_{in} - a + A$$

$$(b) a = g(P_{in})$$

In an ideal system

$$(c) P_o = nP_{in}$$

Let

$$(d) a = mP_{in} + a_o$$

where  $a_o$  is equal to the amplifier gain,  $A$ .

$$(e) P_o = (1-m) P_{in}$$

$$(f) m = 1-n$$

For a square law compressor  $n$  is equal to  $\frac{1}{2}$ .

$$(g) a = \frac{1}{2}P_{in} + a_o$$

For a square law expander  $n$  is equal to 2.

$$(h) a = -P_{in} + a_o$$

## 5. Variable Feedback Compressor or Expander.

Figure 5 is a block diagram of a backward acting compressor or expander in which the gain is varied as a function of the amplifier output by insertion of a variollosser in the feedback path.

$$(a) \beta = f(E_o)$$

$$(b) E_o = \left[ A / (1 + A\beta) \right] E_{in}$$

Assume  $A\beta \gg 1$ .

$$(c) E_o = (1/\beta) E_{in} = \left[ 1/f(E_o) \right] E_{in}$$

Let

number of the vector type. Using the same symbol as in the preceding

example

$$A_{12} = A_{11} + A_{21}$$

$$(A_{11} + A_{21})A_{12} = A_{12}$$

in an ideal system

$$(A_{11} + A_{21})A_{12} = A_{12}$$

Let

$$(A_{11} + A_{21})A_{12} = A_{12}$$

where  $A_{12}$  is equal to the identity  $I$ .

$$(A_{11} + A_{21})I = I$$

$$A_{11} + A_{21} = I$$

For a matrix  $A$  of order  $n$  we have

$$(A_{11} + A_{21})A_{12} = A_{12}$$

where  $A_{12}$  is equal to the identity  $I$ .

$$(A_{11} + A_{21})I = I$$

where  $A_{12}$  is equal to the identity  $I$ .

where  $A_{12}$  is equal to the identity  $I$ .

where  $A_{12}$  is equal to the identity  $I$ .

where  $A_{12}$  is equal to the identity  $I$ .

$$(A_{11} + A_{21})I = I$$

$$(A_{11} + A_{21})I = I$$

$$(A_{11} + A_{21})I = I$$



$$(d) \beta = (1/k) E_o^m$$

$$(e) E_o = (kE_{in})^{1/m+1}$$

In an ideal system

$$(f) E_o = (kE_{in})^n$$

$$(g) m = (1/n) - 1$$

For a square law compressor  $n$  is equal to  $\frac{1}{2}$ .

$$(h) \beta = E_o/k$$

For a square law expander  $n$  is equal to 2.

$$(i) \beta = \frac{1}{k\sqrt{E_o}}$$

Similarly for a forward acting compressor or expander of the variable feedback type (Figure 6.)

$$(j) \beta = (1/k) E_{in}^m$$

$$(k) E_o = kE_{in}^{(1-m)}$$

In an ideal system

$$(l) E_o = kE_{in}^n$$

$$(m) m = 1-n$$

For a square law compressor

$$(n) \beta = (1/k) E_{in}^{\frac{1}{2}}$$

For a square law expander

$$(o) \beta = 1/kE_{in}$$

## 6. Compandor Combinations.

In an ideal system the compressor and expander must be exact complements if the compressed signal is to be perfectly restored by the

$$\begin{aligned} & \lim_{n \rightarrow \infty} \int_0^1 f(x) dx = \int_0^1 f(x) dx \\ & \lim_{n \rightarrow \infty} \int_0^1 f(x) dx = \int_0^1 f(x) dx \end{aligned}$$

In an ideal system

$$\lim_{n \rightarrow \infty} \int_0^1 f(x) dx = \int_0^1 f(x) dx$$

$$\lim_{n \rightarrow \infty} \int_0^1 f(x) dx = \int_0^1 f(x) dx$$

For a system of a certain type, the limit is equal to 1.

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$$\lim_{n \rightarrow \infty} \int_0^1 f(x) dx = \int_0^1 f(x) dx$$

Similarly for a system of a certain type, the limit is equal to 1.

For a system of a certain type, the limit is equal to 1.

$$\lim_{n \rightarrow \infty} \int_0^1 f(x) dx = \int_0^1 f(x) dx$$

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In an ideal system

$$\lim_{n \rightarrow \infty} \int_0^1 f(x) dx = \int_0^1 f(x) dx$$

$$\lim_{n \rightarrow \infty} \int_0^1 f(x) dx = \int_0^1 f(x) dx$$

For a system of a certain type, the limit is equal to 1.

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For a system of a certain type, the limit is equal to 1.

For a system of a certain type, the limit is equal to 1.

For a system of a certain type, the limit is equal to 1.

expander. For this reason symmetrical combinations such as a backward acting compressor and forward acting expander are usually chosen.

expansion. For this reason expansion is not as a backward

acting compression and forward setting expansion and usually occurs.

## CHAPTER V

### 1. Variolosses Design.

The word variolosses is a generic term relating to a circuit whose loss or gain is a function of a control current or voltage. Early variolosses employed the variation in amplification factor of a vacuum tube with bias. Bennett and Doba<sup>5</sup> showed that a linear control current relation to output or input combined with the exponential characteristic of a typical varistor such as copper oxide and germanium diodes is particularly favorable to compression or expansion with a control ratio of one-half. For reasons of space, simplicity, and efficiency the germanium diode is probably the most desirable non-linear element for modern miniaturized compander design.

### 2. Germanium Diode Characteristics.

The static characteristic of a typical germanium diode is plotted in Figure 7. This characteristic may be approximated by  $I = kE^n$ . In variolosses operation, the variation in dynamic resistance of the diode with bias current controls the variolosses attenuation.

$$r = dE/dI$$

$$I = kE^n$$

$$r = R/n$$

where  $r$  is the AC resistance of the diode and  $R$  is the DC resistance of the diode evaluated at a particular bias current. Plots of DC resistance  $R$  vs. DC bias current  $I$  on logarithmic paper for several similar types of diodes indicated that the characteristics were essentially linear but

1. Variable Resistor

The word variable resistor is a generic term relating to a circuit whose resistance or gain is a function of a control current or voltage. Early variable resistors employed the variation in resistance of a carbon track with a wiper contact. Farnett and Tabor<sup>1</sup> showed that a linear control current related to output or input current with the exponential characteristic of a typical variable resistor such as carbon or slide and potentiometer. This is particularly true when the composition of material with a control ratio of one-half. For reasons of space, this study, and efficiency of the variable resistor is not only the most desirable non-linear element for modern electronic circuit design.

2. Characteristics of potentiometers

The static characteristics of a potentiometer are shown in Figure 1. The static characteristics may be approximated by  $I = I_0 \frac{R}{R + R_0}$ , where  $I$  is the current through the potentiometer,  $I_0$  is the current through the potentiometer when the wiper is at the end of the track, and  $R_0$  is the resistance of the potentiometer.

$$I = I_0 \frac{R}{R + R_0}$$

$$I = I_0 \frac{R}{R + R_0}$$

$$I = I_0 \frac{R}{R + R_0}$$

The dynamic characteristics of a potentiometer are shown in Figure 2. The dynamic characteristics may be approximated by  $I = I_0 \frac{R}{R + R_0} \frac{1}{1 + \tau s}$ , where  $I$  is the current through the potentiometer,  $I_0$  is the current through the potentiometer when the wiper is at the end of the track,  $R$  is the resistance of the potentiometer,  $R_0$  is the resistance of the potentiometer, and  $\tau$  is the time constant of the potentiometer.

varied in magnitude and slope. The direct current resistance of a diode at low bias currents can be measured to one percent in a symmetrical Wheatstone bridge.

### 3. Variolosses Configuration.

The simplest form of attenuator is the L type. In a compander the bias current supplied to the non-linear element will vary with the envelope of the input signal; therefore, a balanced form of the L attenuator must be used to prevent unintentional modulation of the signal by AC components of the control bias. This imposes rather severe requirements on the matching of the diodes.

Theoretically the signal voltage drop across each variolosses diode should be small compared to the DC voltage drop to limit the distortion introduced by the non-linearity of the diode characteristic. In a balanced circuit the second harmonic distortion will cancel. Preliminary measurements indicated that the third harmonic would be more than 40db below the fundamental if the peak to peak signal voltage was limited to one-half the DC voltage.

In the Lenkurt compander a 28 db range of attenuation was required in both the compressor and expander variolosses. A two section balanced L type attenuator was found to be necessary to cover this range.

### 4. Design Procedure.

The mathematical analysis of two terminal varistor variolosses by Bennett and Doba<sup>5</sup> imposed simplifying conditions that were not compatible with the problem at hand. The mathematical approach was therefore abandoned in favor of a graphical method.

varied in magnitude and slope. The direct current resistance of a single  
at low bias currents can be measured to one percent in a symmetrical bridge  
stone bridge.

### 3. Nonlinear Characteristics

The simplest form of attenuator is the  $I^2$  type. In comparison the  
bias current applied to the non-linear element will vary with the square  
slope of the input signal; therefore, a balanced form of the  $I^2$  attenuator  
will be used to prevent unintentional modulation of the signal. It is  
possible of the control bias. This imposes a linear relationship on  
the definition of the bias.

When the signal voltage drops across a non-linear element, the  
signal is not only reduced in the  $I^2$  voltage drop is linear the distortion  
introduced is the non-linearity of the element after rectification. In a bal-  
anced circuit the even harmonics distortion will cancel. Rectification  
characteristics of the non-linear element would be less than 80dB  
before all the signal in the peak to peak signal voltage was limited to  
one-half the  $I^2$  voltage.

The non-linear element is a  $I^2$  type of non-linearity was required  
in the design of the non-linear element. A non-linear element  
was used to provide the non-linear element.

The non-linear element is a  $I^2$  type of non-linearity was required  
in the design of the non-linear element. A non-linear element  
was used to provide the non-linear element.



The bias current,  $I_{DC}$ , was selected as a parameter. Curves of load current vs. power input in dbm for a full wave rectifier with condenser input were determined experimentally for various resistance loads in series with a diode to simulate the load presented by a variolossor. Increase in diode resistance with decrease in current, decrease in rectifier efficiency with decrease in current, and variation of mismatch between generator internal impedance and equivalent load resistance resulted in varying departure from linearity over the input range. By comparison of these power vs. current curves with computed attenuation vs. current curves of a two section L attenuator, curvature of the attenuator characteristic at low bias currents could be made to balance the curvature of the power curve, when the diodes were used as shunt attenuator elements.

#### 5. Compressor Variolossor.

By the methods outlined in section 4, approximate component values were selected. An input transformer turns ratio was specified to reflect a nominal impedance of 600 ohms to the primary. A series of experimental curves of attenuation vs. power input were then run using the circuit of figure 8. Measured characteristics deviating less than one db from the ideal were obtained.

#### 6. Expander Variolossor.

The expander variolossor was designed to be the inverse of the compressor variolossor. A two section balanced L type attenuator was used with the diodes as series element. Comparison of control rectifier power vs. current curves with computed attenuation vs. current curves of the attenuator indicated the curvature of the attenuator characteristic at

The three current, <sup>XX</sup> was selected as indicated on the attached map.

[illegible]

2. Содержание 10

1. The following information was obtained from the records of the Department of the Interior, Bureau of Land Management, regarding the land owned by the United States in the State of California:

1990

- a letter to the President of the United States, dated 1941, in which the President is advised that the Government is not in a position to provide for the needs of the people of the United States, and that the Government is not in a position to provide for the needs of the people of the United States, and that the Government is not in a position to provide for the needs of the people of the United States.

low current values would not be compensated for by curvature of the power vs. current characteristic. By empirical methods the circuit of figure 9 was devised. Since the attenuation was increasing too rapidly at low bias current values, the logical solution was a fixed resistor shunt around the series diodes. Computation of the value of this shunt was not attempted due to complex characteristic of a non-linear element shunted by a linear resistance. Attenuation vs. power input characteristics varying less than one db were obtained. By fortunate coincidence the deviation of the compressor and expander characteristics from the ideal tended to cancel at high signal levels thereby resulting in a superior system characteristic.

#### 7. Diode Selection.

As is well known present production runs of germanium diodes vary widely in characteristics. For successful mass production of varielossers a rapid method of selecting matched diode quads is necessary.

As has been shown in section 2, the dynamic resistance of an idealized diode is a constant times the static resistance of the diode at a specified value of bias current. Since the problem of diode selection is primarily one of grouping diodes of matched characteristics rather than precise determination of their characteristics, a selection process based on measurement of DC resistance was decided upon.

The most simple and accurate way of measuring DC resistance of a diode is with a symmetrical Wheatstone Bridge. The power source for the bridge may be a 45 volt "B" battery with adjustable series resistance to limit the current flowing thru the bridge to twice the desired bias current. Since the

low current values would not be compensated for by curvature of the power vs. current characteristic. By empirical methods the circuit of Figure 1 was devised. Since the characteristic was inoperative for low bias current values, the logical solution was a fixed resistor placed across the series diodes. Compensation of the value of this resistor was not attempted due to complex characteristic of a non-linear element connected in a linear resistance. Attention vs. power input characteristics varied less than one db were obtained. By fortunate coincidence the deviation of the power resistor and expansion characteristics from the ideal tended to cancel at high signal levels thereby resulting in a superior power characteristic.

### 3. Diode Selection

As is well known present production runs of germanium diodes vary widely in characteristics. For satisfactory power reduction of varactors a rapid method of selection method diodes is necessary. As has been shown in Section 2, the dynamic resistance of an idealized diode is a constant times the static resistance of the diode at a specified value of bias current. Hence the problem of diode selection is reduced to one of finding a method of selecting diodes which have a constant dynamic resistance. A method of selection, a detailed description of which is given in Section 4, was used to select diodes for the circuit of Figure 1. The results of this selection are shown in Figure 2. It is seen that the dynamic resistance of the selected diodes is constant within 1 db over the entire range of bias current. This is a very important characteristic for the circuit of Figure 1.

resistance measurements are made at 500 micro-amperes and 10 micro-amperes diode current, the combination of a high voltage battery and a high series resistor is approximately a constant current source. Due to symmetry of the bridge the current will divide equally between the two arms of the bridge.

Although the bridge method is satisfactory for laboratory use, a more rapid method is required for production testing. For reasons of economy, an operator with no technical training should be able to group several thousand diodes daily. With this requirement in mind a specialized series type ohmmeter was assembled. From knowledge of actual diode resistance measured by the bridge method equivalent battery voltage and series dropping resistance were selected to give a mean diode current of 500 micro-amperes. The meter scale was then blocked off into eight 10 micro-ampere sections lettered A thru H. A similar ohmmeter was assembled to give a mean current of 10 micro-amperes with the meter scale blocked off into eight 0.2 micro-ampere sections lettered A thru H. Actual plots of some thirty diode characteristics indicated that a two point selection scheme would be adequate.

The diodes were then divided into eight groups on the basis of their resistance at 500 micro-amperes. Each group obtained was then divided into eight sub-groups on the basis of their resistance at 10 micro-ampere resistance. The end result was sixty-four possible diode groups identified by rectangular coordinates; i.e. AB, CC, etc. The adequacy of the system was checked by successful operation of diodes so selected in compandor variolossers.

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The diodes were then divided into eight groups on the basis of their resistance at 500 micro-amperes. Each group of diodes was then divided into eight sub-groups on the basis of their resistance at 10 micro-amperes. A sample of 100 diodes was selected from each of the 64 sub-groups. The mean resistance of the 100 diodes was 1.4 ohms. The standard deviation of the resistance was 0.1 ohms. The mean resistance of the 100 diodes was 1.4 ohms. The standard deviation of the resistance was 0.1 ohms.

## CHAPTER VI

### 1. Control Rectifier Design:

Basically the control rectifier is an envelope detector. The most important design characteristics are the attack time and the recovery time. Attack time is determined primarily by the equivalent source resistance of the signal circuit driving the rectifier. Previous experience has indicated that an attack time of from 5 to 20 milliseconds is satisfactory.<sup>6</sup> The complex envelope of speech makes the precise determination of optimum attack time impossible. An indication of a suitable value can only be made on the basis of listening tests made by experienced telephone engineers.

Suitable values for recovery time have been determined by listening tests to be of the order of 100 milliseconds.<sup>6</sup> Too short values of recovery time result in "thump" as the compressor variolossor reduces loss rapidly at the end of a speech burst. The optimum value can only be determined by extensive listening tests by skilled personnel.

### 2. Rectifier Filter Circuit:

The simplest circuit which will meet the above timing specifications is a shunt capacitor followed by a series resistor. Ideally the series resistor should be large in comparison with the static resistance of the variolossor in order that the variolossor bias current will be a linear function of the input voltage. In practical circuit design this characteristic must be compromised due to limitation in available driving voltage. Some control over the output current versus input power to the

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Basically the control reaction is an envelope detector. The most important design considerations are the attack time and the recovery time. Attack time is determined primarily by the equivalent source resistance of the signal circuit driving the rectifier. Previous experiments have indicated that an attack time of from 1 to 50 milliseconds is satisfactory. The control envelope of speech waves has precise definition of optimum attack time impossible, an indication of a suitable value can only be made on the basis of listening tests made by experts and a listening experiment.

[illegible]

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rectifier is possible by specification of the rectifier transformer turns ratio.

The equivalent load impedance presented at the primary of the rectifier input transformer is meaningless due to the complex waveform produced by the non-linear rectifier elements. An experimental determination of maximum power transfer using a 1000 cycle source indicated that for a load of given resistance, maximum power will be delivered to the load when the equivalent generator impedance at 1000 cycles is of the order of the load resistance. If a center-tapped full wave rectifier transformer is used, allowance must be made for the fact that only half of the transformer is active at any one instant.

By use of the above principles rectifier transformers were specified for maximum efficiency by matching the generator resistance to the variolossor load at maximum bias current values. Due to curvature of the power transfer characteristic a desirable low ratio of maximum to minimum bias current was also obtained over the control range of the compander.

### 3. Rectifier Isolation:

As is well known, the input to a full wave rectifier with condenser input filter is rich in odd order harmonics. In a compander design some method of isolating the signal path from this rectifier distortion must be provided. An excellent system is the use of an isolating control rectifier.<sup>4</sup> To facilitate miniaturization, the Lenkurt compander employs a hybrid junction for isolation purposes. Attenuation of the third harmonic distortion components to 50 db below the fundamental were obtainable

rectifier is possible by specification of the rectifier transformer  
turns ratio.

The effective load impedance presented at the primary of the  
rectifier input transformer is magnified due to the higher wave-  
form produced by the non-linear rectifier elements. An equivalent  
determination of maximum power transfer using a 100% ripple source in-  
dicates that for a load of given resistance, maximum power will be de-  
livered to the load when the equivalent transformer impedance at 100% cy-  
cle is of the order of the load resistance. In a center-tapped full-  
wave rectifier transformer is used, allowance must be made for the fact  
that only half of the transformer is active at any one instant.  
By use of the above techniques rectifier transformers may be specified  
for optimum efficiency by matching the generator voltage and the recti-  
former load at a suitable power factor value. In the case of the power  
factor being a variable low value, it is better to specify the  
current to be obtained over a control range of comparison.

#### V. Rectifier Load

It is assumed that the load is a non-linear rectifier which may have  
a variable impedance. The load is assumed to be a non-linear rectifier  
which may have a variable impedance. The load is assumed to be a non-linear  
rectifier which may have a variable impedance. The load is assumed to be a  
non-linear rectifier which may have a variable impedance. The load is  
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a variable impedance. The load is assumed to be a non-linear rectifier  
which may have a variable impedance. The load is assumed to be a non-linear  
rectifier which may have a variable impedance. The load is assumed to be a  
non-linear rectifier which may have a variable impedance. The load is  
assumed to be a non-linear rectifier which may have a variable impedance.

by this method with a considerable saving in the number of components.

#### 4. Transformer and Resistance Hybrid Junctions.

The literature contains very few references to hybrids although they are extensively used in the telephone industry. In recent years the principle has been extended to microwave frequencies. Basically the hybrid can be represented as an eight terminal network. (Figure 10) When driven from any pair of terminals, power will be transmitted to the two adjacent pairs of terminals but not to the opposite pair of terminals. The network may be designed for a specified division of power between the two transmission paths. This characteristic is particularly desirable in compander design as the greater portion of power can be transmitted to the control rectifier. Since the variolosses must be operated at a low level for minimum distortion, the resultant attenuation in the signal path is compatible with the design requirements.

The hybrid is a bilateral device and must be terminated in its characteristic impedance at both sending and receiving ends to prevent reflection of power. In the case of a forward acting compressor or expander the driving circuit impedance may not always be under the control of the designer. For example, in the Lenkurt 45A System the expander was driven from a low pass voice frequency filter. In the range from 250 cycles to 3500 cycles the filter was designed to present an equivalent source impedance of 600 ohms to match in the expander input. Outside this band the equivalent source impedance would approach zero or infinity depending on the particular filter configuration. Since the control rectifier generates

by this method with a considerable margin in the amount of time.

...and I have lived with you for the past 10 years.

The literature contains very few references to high speed relays. In recent years they are extensively used in the telephone industry. The principle has been extended to microwave transmission. It is usually the hybrid one is represented as an eight terminal network. (Figure 10) When driven from any pair of terminals, power will be transmitted to the two adjacent pairs of terminals but not to the opposite pair of terminals. The network can be designed for a specified division of power between the two transmitting pairs. This characteristic is particularly desirable in a computer design as the greatest portion of power can be transmitted to the output terminals. When the transmission is carried out at a low level for high speed operation, the transmission is not subject to the same losses as in the case of the hybrid relay.

The report is a technical device and not a pamphlet in the sense of a political device and not a pamphlet in the sense of a political device.

an appreciable third harmonic, this harmonic will lie outside the filter pass band. This harmonic will be transmitted back to the source and reflected from the source into the signal path. To attenuate this harmonic to an acceptable level a resistance hybrid was employed with a loss of 8 db in the rectifier transmission path. The 8 db value was determined experimentally using a signal source of low impedance to provide a reflection coefficient at the generator of approximately one.

an appreciable third harmonic, this harmonic will lie outside the filter pass band. This harmonic will be transmitted back to the source and reflected from the source into the signal path. To suppress this harmonic to an acceptable level a resistance hybrid was employed with a loss of 8 db in the reflector transmission path. The 8 db value was determined experimentally using a signal source of low impedance to provide a reflection coefficient of approximately one.

## CHAPTER VII

### 1. Amplifier Design:

The amplifiers in the compandor are of conventional design. For reasons of reliability and ease of maintenance, tube types in the 45A system were limited to the 6AK5 pentode and Western Electric 2C51 twin triode. To obtain the required gain of 50 db for the compressor amplifier a two stage transformer coupled amplifier using a 2C51 was used. In the expander amplifier resistance-capacitance interstage coupling was used as a gain of only 40 db was required. Miniaturized transformers measuring three quarters of an inch on a side were specially designed for the compandor. Further savings in space were made by reducing the design to the minimum number of parts. Cathode bypass capacitors were eliminated by using small cathode resistors to reduce the degeneration and obtaining the required operating bias by a voltage divider from the plate supply. The use of printed circuits was studied but rejected due to wide tolerance of available printed components. To meet production specifications, components of 5% tolerance were required.

### 2. Use of Negative Feedback:

To insure that the amplifier gain would remain within acceptable limits with aging of tubes and components a minimum of 14 db of overall feedback was specified. A combination of current and voltage feedback was used to adjust the amplifier output impedance to exactly 600 ohms. Matching of impedances for maximum power transfer is common practice in carrier systems. Use of a large value of overall feedback made the use of miniature trans-





formers possible while maintaining the amplifier response flat within one half db over the voice frequency range of 250 to 3500 cycles.

to be possible while maintaining the regular service

and held it over the winter season of 1911-12.

## CHAPTER VIII

### 1. Steady State Testing Techniques:

In preliminary testing of the compandor a high quality sine wave generator was used as a signal source. According to design specifications, the compressor and expander control ratios shall not vary more than plus or minus one half db from the ideal over the control range of 58 db. The overall system characteristic shall be flat within one db over the same range. The system frequency response shall be flat within one half db over the range from 250 to 3500 cycles. Harmonic distortion components shall be at least 40 db below the fundamental. All measurements are to be accurate to within 0.1 db.

To obtain measurements of satisfactory accuracy, precision decade attenuators calibrated in 0.1 db steps were used in conjunction with a Hewlett Packard 400C AC vacuum tube voltmeter as a balance indicator. Harmonic distortion measurements were made with a wave analyzer.

### 2. Dynamic Testing Techniques:

Actual operation of the compandor is more a function of the system transient response than its steady state response. Determination of satisfactory operation of the compandor was made by actual listening tests. Repetitive phrases from a closed loop on a tape recorder were used as a test signal. By means of an "A-B" test panel, the operator could switch from a compandor channel to a conventional channel. From two to four compandors were connected in tandem to magnify any inherent faults. To minimize the human element the two transmission channels were identified to the operator only

## CHAPTER VIII

### 1. Steady State Testing Technique

In preliminary testing of the compressor a high quality air was  
compressor was used as a signal source, according to design specifications,  
the compressor and expansion control ratios shall not vary more than plus or  
minus one half of the total over the entire range of 50 to 100. The over-  
all system characteristics shall be that within one half over the same range.  
The static pressure response shall be that within one half over the  
range from 25 to 100 cycles. Dynamic characteristics shall be as  
described in 2.1.1. All measurements are to be accurate to  
within 0.1%.

2. Steady State Testing Technique

3. Steady State Testing Technique

4. Steady State Testing Technique

5. Steady State Testing Technique

6. Steady State Testing Technique

7. Steady State Testing Technique

8. Steady State Testing Technique

9. Steady State Testing Technique

10. Steady State Testing Technique

as Channel A and Channel B. When a number of experienced telephone engineers could not consistently identify the companded channel, the operation of the compandor was considered satisfactory.

Measurement of actual noise advantage is made in a similar qualitative manner. A noise source is introduced into the compressed section of the compandor transmission path. A similar noise source in the conventional path is then adjusted by the operator until he estimates it to be of the same level as the noise in the compandor path. The observations of a group of at least twenty five operators are then averaged. A compandor noise advantage of about 22 db was established by the Bell Telephone Laboratories with this method<sup>1</sup>.

as Channel A and Channel B. When a number of a recorded telephone call-  
ners could not consistently identify the compared channel, the opera-  
tion of the comparator was considered satisfactory.  
Measurement of actual noise advantage is made in a similar manner.  
five manner. A noise source is introduced into the compressed section of  
the compressor transmission path. A similar noise source in the conven-  
al path is then adjusted by the operator until he estimates it to be of the  
same level as the noise in the compressor path. The observation of a group  
of at least twenty-five operators are then averaged. A compressor noise  
advantage of 0.5 to 0.8 dB was established by the Bell Telephone Laboratories  
with this method.

## CHAPTER IX

### 1. Benefits of the Compander:

Theoretically the use of companders of high control ratio would provide large noise advantage on transmission circuits. For a square law compander the advantage would be equal to the maximum compressor gain or 28 db. Since the operation with complex signal input deviates from the ideal steady state sine wave input, actual noise advantage has been found to be of the order of 22 db regardless of control ratio.

Due to the noise reduction many channels unsuited for conventional operation become usable with the application of companders. For example lines transposed for carrier frequencies up to 35 kc ordinarily need reworking to prevent objectionable cross talk if higher frequency carrier systems are added. In practice these lines have been found usable with high frequency carrier systems employing companders. For the same reasons voice frequency lines are often suitable for carrier frequencies up to 35 kc with a compander system.

### 2. Application of Companders to Radio Circuits:

Multi-channel radio links using companders with the carrier equipment can have lower fading margins, longer transmission paths, and greater number of repeaters because of the additional signal to noise advantage of the compander. In conventional amplitude modulated or single sideband radio transmitters an appreciable increase in equivalent power can be achieved due to the decreased ratio of peak to average power in compressed speech.





### 3. Savings in Manufacturing Costs:

Substantial savings can often be made in manufacturing costs when carrier systems are designed with integral compandors. Design specifications of line filters, channel filters, and directional hybrids can often be relaxed. Repeater spacing may also be increased.

### 4. Compandor Applications:

Past applications of compandors have been limited to telephone circuits and a few long distance radio links. Suggested military applications are ship to ship, ship to shore, and ship to airplane VHF voice circuits. A suitable compandor operating over a limited video band would improve the performance of radar telemetering relay links. Intelligent use of compandors may assist materially in solving present overcrowding of available communication channels.

3. Savings in Manpowering Costs:

Substantial savings can often be made in manning costs when carrier systems are designed with internal components. Design specifications of line filters, channel filters, and directional hybrids can often be relaxed. Repetitive spacing may also be increased.

4. Component Amplification:

Test applications of components have been limited to telephone circuits and a few long distance radio links. Proposed military applications are ship to ship, ship to shore, and shore to shore voice circuits. A suitable component operating over a limited voice band would improve the performance of radio links. Further delay links. Intelligent use of components may result in saving of manpowering costs in radio communication systems.

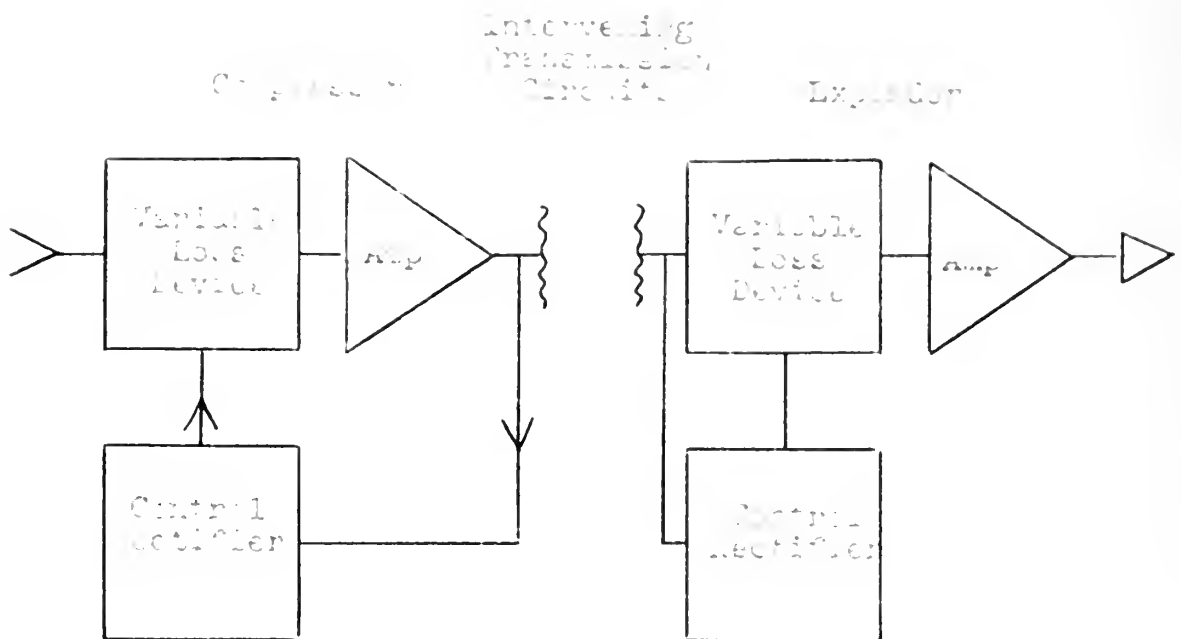


Figure 1. Block diagram of a transmission system with feedback loops for both compressor and expander. The system consists of a variable loss device, an amplifier, and a control rectifier.

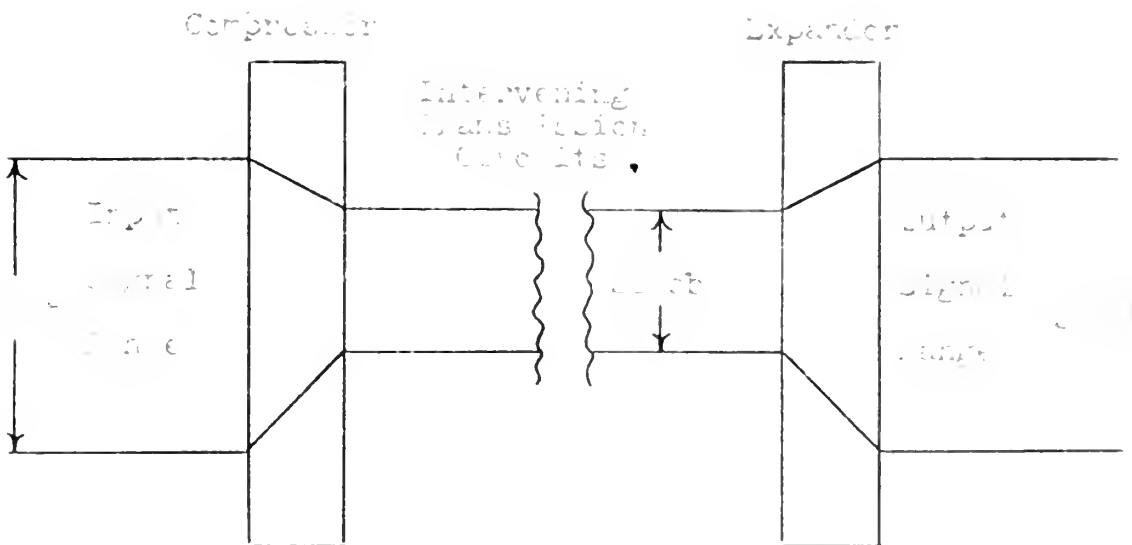


Figure 2. Block diagram of a transmission system with feedback loops for both compressor and expander. The system consists of a variable loss device, an amplifier, and a control rectifier.



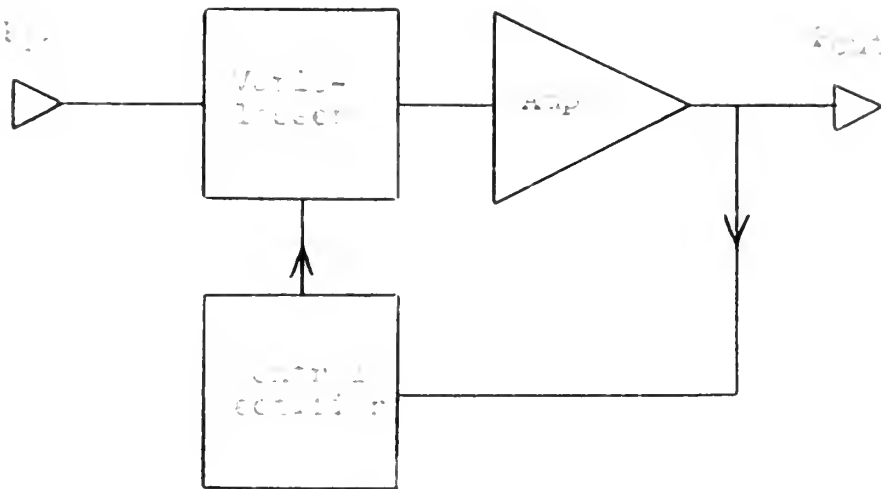


Figure 5. Block diagram of automatic actuating compressor or expansion.

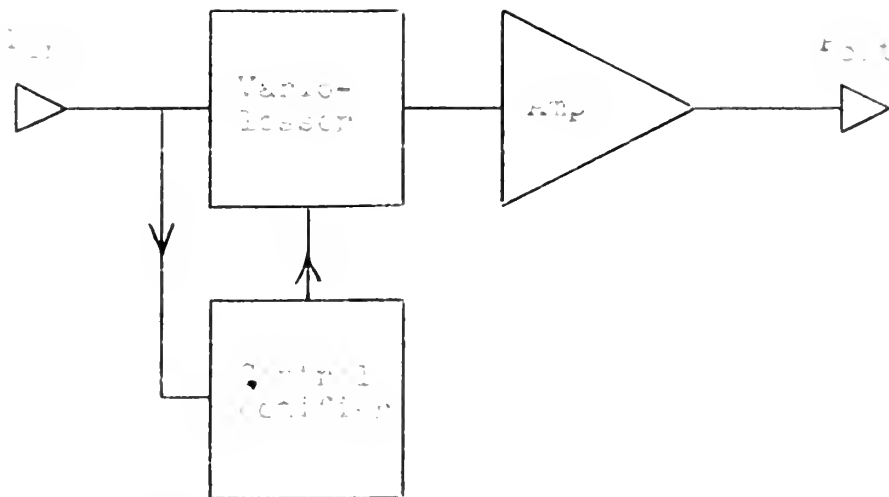


Figure 6. Block diagram of automatic actuating compressor or expansion.



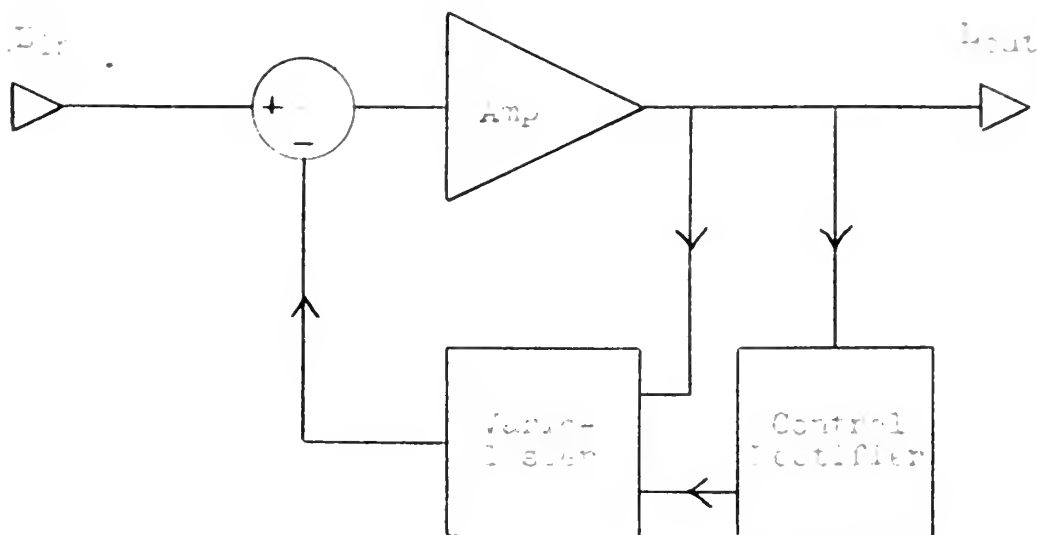
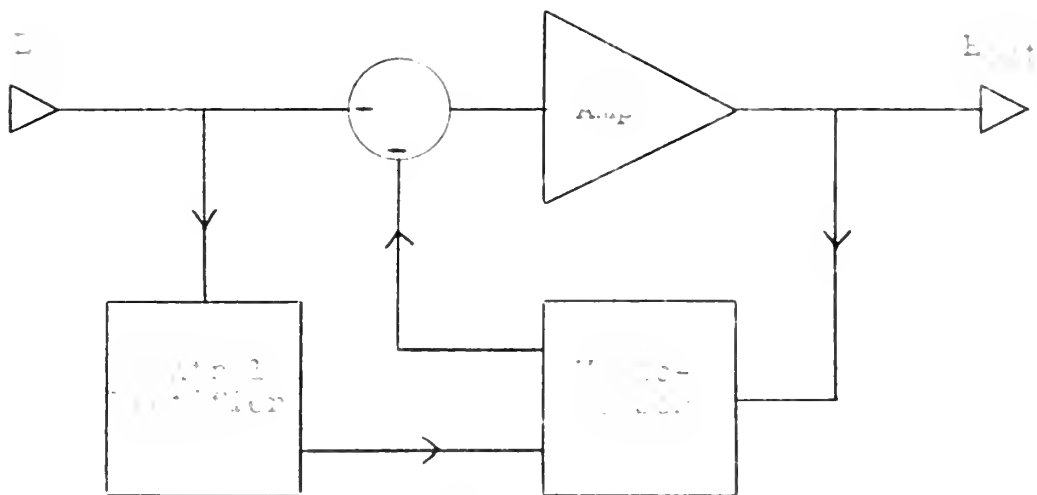


Figure 5. Block diagram of variable feedback backward acting compressor or expander.







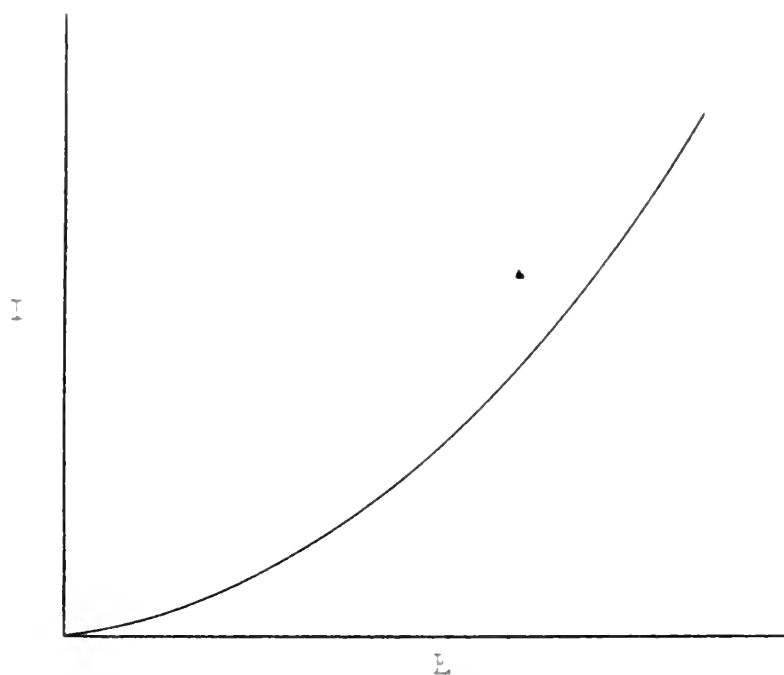
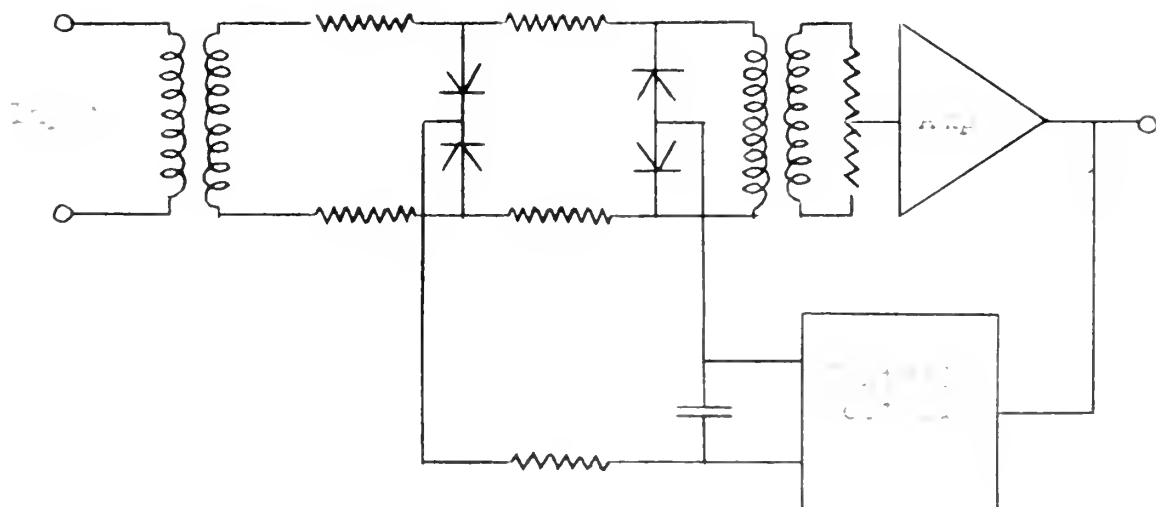


Fig. 16. Static characteristic of the device.





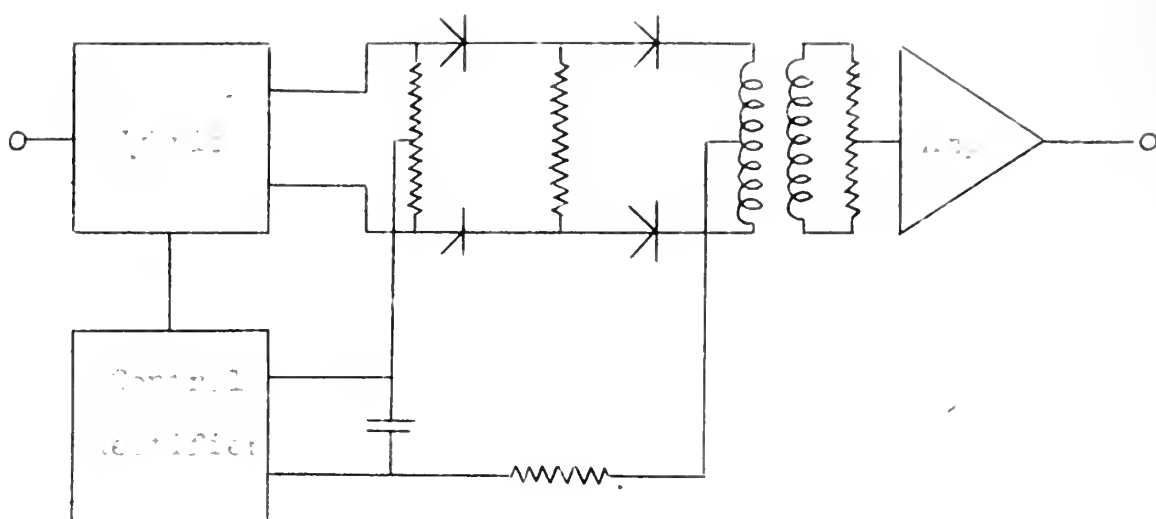
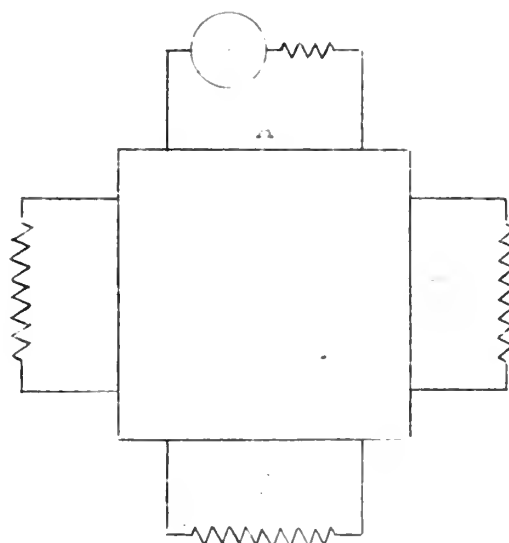


Figure 2. Diagram of the circuit of the experimental setup.





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